

Visible and near-infrared observations of asteroid 2012 DA₁₄ during its closest approach of February 15th, 2013

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ABSTRACT

Context. Near-Earth asteroid 2012 DA₁₄ made its closest approach on February 15th, 2013, when it passed at a distance of 27,700 km from the Earth's surface (inside the geosynchronous satellite ring). It was the first time an asteroid of moderate size was predicted to get that close to the Earth, becoming bright enough to permit a detailed study from ground based telescopes.

Aims. Asteroid 2012 DA₁₄ was poorly characterized before its closest approach. The main objective of this work was to obtain new and valuable data to better understand its physical properties, and to evaluate the effects of such a close approach on the object.

Methods. We acquired data using several telescopes on four Spanish observatories: the 10.4m Gran Telescopio Canarias and the 3.6m Telescopio Nazionale Galileo, both in “El Roque de los Muchachos” Observatory (ORM, La Palma); the 2.2m CAHA telescope, in “Calar Alto” Observatory* (Almería); the f/3 0.77m telescope in “La Hita” Observatory (Toledo); and the f/8 1.5m telescope in “Sierra Nevada” Observatory (Granada). We obtained visible and near-infrared colour photometry, visible spectra and time-series photometry.

Results. Visible spectra together with visible and near-infrared color photometry of 2012 DA₁₄ show that the object can be classified as an L-type asteroid, a not very common spectral type among the asteroid population. The time-series photometry indicates a rotational period around 9 hours, and the large amplitude of the variation suggests that the object is very elongated and irregular, with an equivalent diameter around 22m. We obtain an absolute magnitude of $H_R = 24.1 \pm 0.2$, corresponding to 24.6 ± 0.2 in V. From the absolute photometry, together with some constraints on size and shape, we compute a geometric albedo of $p_V = 0.34 \pm 0.20$.

Key words. minor planets, asteroids: individual: 2012 DA₁₄ – methods: observational – techniques: photometric, spectroscopic

1. Introduction

Asteroid 2012 DA₁₄ (hereafter DA14) is a near-Earth object first discovered on February 23rd at La Sagra Observatory, in Spain (see Minor Planet Electronic Circular MPEC 2012-D51 for

* Based on observations collected at the German-Spanish Astronomical Center, Calar Alto, jointly operated by the Max-Planck-Institut für Astronomie Heidelberg and the Instituto de Astrofísica de Andalucía (CSIC).

Table 1. Observational details of the color photometry and spectroscopy data. All the data was obtained with distance to the Sun $r = 0.988$ AU. The UT corresponds to the middle exposure time, and in all cases refers to February 16.

Photometry								Spectroscopy				
Filter	λ_c (μm)	UT	Exp. (secs)	Airm.	Δ (AU)	α ($^\circ$)	Magnitude	UT	Exp. (secs)	Airm.	Δ (AU)	α ($^\circ$)
OSIRIS-GTC								CAFOS-CAHA				
g'	0.48	01:08	1	1.86	0.00093	73.09	12.22 ± 0.02	00:40	60	1.45	0.00085	72.00
		05:18	4x5	1.90	0.00156	77.68	14.21 ± 0.03	00:44	60	1.45	0.00087	72.17
r'	0.64	01:07	1	1.86	0.00092	73.06	11.50 ± 0.02	00:47	60	1.45	0.00088	72.29
		05:20	4x1	1.90	0.00157	77.70	13.59 ± 0.03	00:50	60	1.45	0.00088	72.42
i'	0.77	01:08	1	1.86	0.00093	73.09	11.32 ± 0.03	02:37	120	1.49	0.00115	75.51
		05:22	4x1	1.90	0.00157	77.71	13.44 ± 0.03	02:41	120	1.49	0.00116	75.59
z'	0.96	01:09	1	1.86	0.00093	73.13	11.22 ± 0.03					
		05:25	4x3	1.90	0.00158	77.74	13.37 ± 0.02					
NICS-TNG								OSIRIS-GTC				
1mic	1.02	05:32	10x10	1.90	0.00160	77.79	12.69 ± 0.04	05:30	90	1.90	0.00159	77.78
J	1.27	05:37	10x10	1.90	0.00161	77.83	12.47 ± 0.06					
H	1.60	05:42	10x10	1.90	0.00162	77.87	12.25 ± 0.06					
K	2.2	05:47	10x10	1.90	0.00163	77.91	12.29 ± 0.08					

further details¹). This Apollo near-Earth asteroid focused the attention of the scientific community when it made its closest approach to the Earth on February 15th, 2013, at 19:26 UT. It passed at a distance of 27,700 km from the Earth's surface, inside the geosynchronous satellite ring. Asteroid DA14 is poorly characterized. Prior to the closest approach there was information scattered on the internet about a possible L spectral type for DA14 and a possible rotation period around 6 hours, but this information had not been published in any journal or scientific publication. According to the value listed by the Minor Planet Center (MPC) it has an absolute magnitude of $H = 24.4$ and a diameter of ~ 50 m, assuming a geometric albedo of 20%, which is an average albedo for asteroids. This introduces an error in diameter around a factor of two, and even a larger uncertainty in the estimation of the asteroid mass.

Close approaches of asteroids to the Earth are interesting events because the object can potentially break up due to tidal forces if they reach the Roche limit. They can even be a mechanism for the formation of binaries (e.g. Walsh & Richardson 2006) and perhaps asteroid pairs. Besides, in general, interchanges of linear and angular momentum between the Earth and the approaching body are processes that have an effect on the population of Near Earth Objects by altering their orbits and their physical properties. For those reasons, we took advantage of DA14's closest approach to Earth on February 15th, 2013 to obtain highly complementary data (visible and near-infrared colour photometry, visible spectroscopy, and time-series photometry) using the telescopes located in four Spanish observatories: the 10.4 m Gran Telescopio Canarias (GTC) and the 3.6 m Telescopio

¹ <http://www.minorplanetcenter.net/mpec/K12/K12D51.html>

Nazionale Galileo (TNG), both located at “El Roque de los Muchachos” Observatory (ORM), in the island of La Palma; the 2.2m CAHA telescope located at “Calar Alto” Observatory, in Almería; the f/3 0.77m telescope at “La Hita” Observatory, in Toledo; and the f/8 1.5m telescope in “Sierra Nevada” Observatory (OSN), in Granada.

2. Observations and data reduction

We arranged an observational campaign to characterize DA14 during its closest approach on the night of February 15th to 16th, 2013. During the observations the asteroid’s proper motion, which was quite high, varied from almost 4″/sec to 0.5″/sec, imposing a technical challenge for the telescopes and the observers.

2.1. Colour photometry

Broad band photometry of DA14 was obtained using the Optical System for Imaging and Low Resolution Integrated Spectroscopy (OSIRIS) camera-spectrograph (Cepa et al. 2000; Cepa 2010) at the GTC. The OSIRIS instrument consists of a mosaic of two Marconi CCD detectors, each with 2048 x 4096 pixels and a total unvignetted field of view of 7.8 x 7.8 arcmin, giving a plate scale of 0.127 arcsec/pix. The CCD was binned in 2 x 2 pixels, as corresponds with the standard operation mode of the instrument. Observations were done under photometric conditions, dark moon, and an average seeing of 2.0″. For broad band imaging, two different series in Sloan g' , r' , i' , and z' filters were obtained. Observational details are summarized in Table 1, where we show the mid exposure UT time of each observation, the airmass, the distance to the Sun (r) and to the Earth (Δ), and the phase angle (α). Bias correction, flat fielding and bad pixel masking were done using standard procedures, and the images were finally aligned to perform the photometric measurements. Images were calibrated using Sloan photometric standards and average extinction coefficients (following the instructions on the OSIRIS user manual²). The obtained magnitudes on each filter are shown in Table 1.

Broad band photometry in the near-infrared was performed using NICS camera-spectrograph (Baffa et al. 2001) at the TNG. The plate scale was 0.25 arcsec/pixel, yielding a field of view of 4.2 x 4.2 arcmin. The series of images through a custom filter centered at 1.02 μm (1mic) and the standard Johnson J, H, and K filters consisted of 10 individual exposures of 10 secs following a dithering pattern on different positions on the CCD, separated by offsets of 10 pixels. The tracking of the telescope was at the proper motion of the target. Each frame was first corrected for cross-talk using the routines provided on the TNG web page³. The data were then reduced in the standard way using IRAF routines. All the frames were flat-field corrected and sky subtracted. Standard aperture photometry was done. We observed two fields of standard stars for calibration, using a mosaic of 5 individual exposures of 10 secs for P177-D and 5 secs for P041-C (Persson et al. 1998). The resulting magnitudes are shown in Table 1 together with the observational details.

² www.gtc.iac.es/instruments/osiris/osiris.php

³ <http://www.tng.iac.es>

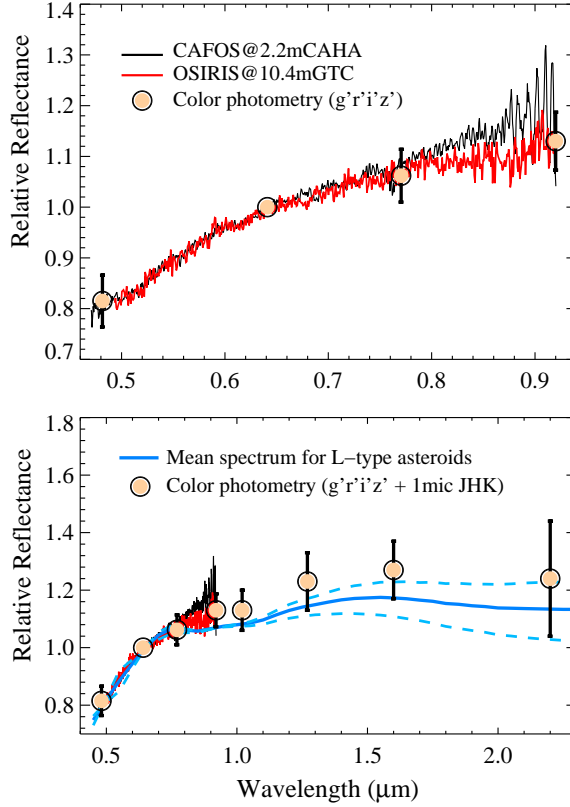


Fig. 1. *Top panel.* Visible spectra of DA14 obtained with CAFOS (black) and the OSIRIS (red). Filled circles are the reflectance R values computed from the visible colours. *Bottom panel.* Same as the top panel, but adding the reflectance values computed from near-infrared colors obtained with NICS. The mean spectrum of L-type asteroids from DeMeo et al. (2009) is shown in blue. Light-blue dashed lines indicate the variation range of this mean spectrum. Both the spectra and the reflectance R are normalized to unity at the central wavelength of r' .

2.2. Visible spectroscopy

A visible spectrum of DA14 in the 0.49–0.92 μm range was obtained with OSIRIS-GTC using the R300R grism and a 10'' slit in order to minimize possible slit losses due to atmospheric dispersion. The R300R grism provides a dispersion of 7.64 $\text{\AA}/\text{pixel}$. Observational details are shown in Table 1. Images were bias and flat-field corrected, using lamp flats. The two-dimensional spectra were wavelength calibrated using Xe+Ne+HgAr lamps. After the wavelength calibration, sky background was subtracted and a one dimensional spectrum was obtained. To correct for telluric absorption and to obtain the relative reflectance, solar analogue star SA110-163 from the Landolt catalogue (Landolt 1992) was observed using the same spectral configuration at an airmass nearly identical to that of the object. The spectrum of the object was then divided by the corresponding spectrum of the solar analogue, and normalized to the central wavelength of the r' filter (0.64 μm). The resulting final reflectance spectrum is shown in Fig. 1.

Another series of visible spectra of DA14 were obtained on the same night using the Calar Alto focal reducer and faint object spectrograph CAFOS instrument. CAFOS is equipped with a 2048x2048 pixel blue-sensitive CCD and a plate scale of 0.52''/pixel. We used the R-400 grism, giving a wavelength coverage from about 0.45 to 0.93 μm , and a dispersion of 9.7 $\text{\AA}/\text{per pixel}$

($R \sim 400$). A 2'' slit was employed. The tracking was at the asteroid's proper motion and the slit was oriented in the direction of asteroid's motion to minimize slit losses. Six individual spectra were obtained (see details in Table 1). Pre-processing of the CCD images included bias and flat-field correction. A one-dimensional spectrum was extracted from 2-D images, and wavelength calibration was applied using Cd, Hg, and Rb lamps. All the spectra were corrected from atmospheric extinction. To obtain the asteroid's reflectance spectra we observed solar analogue star BS4486. The final visible spectrum is the average of the six individual spectra and normalized to unity at the central wavelength of the r' filter (black line in Fig. 1).

2.3. Time series photometry

The time series photometry was obtained from CCD images acquired at the remotely operated f/3 0.77m telescope in "La Hita" Observatory. The images were obtained using exposure times of 1 and 2 secs by means of a thermoelectrically cooled 4k x 4k CCD that provides a field of view of 47.9 x 47.9 arcmin and using a Luminance filter. Binning 2x2 was used, yielding a resolution of 1.42 arcsec/pixel, and the telescope was tracked at sidereal rate. The object was observed in 29 different star fields. The observations started approximately 2 hours after closest approach and finished almost at dawn, spanning ~9 hours. There was a 1.3 hour gap in the acquisition due to a network problem that prevented remote operations. More than 1600 images were processed. The images were dark subtracted and flat-fielded. The flux of the asteroid was obtained through synthetic apertures, changed along the image sequence to accommodate to the different trail lengths. Twenty four comparison stars were measured in each image, with identical apertures to that used for the asteroid, to monitor possible atmospheric transparency fluctuations. Zeropoints for the photometry were obtained for each field using USNOB1 stars. The magnitudes were corrected for the changing heliocentric (r) and geocentric (Δ) distance of DA14 during the observations. We also applied the phase angle correction using Bowell's G,H formalism (Bowell et al. 2002) and the value of $G=0.15$ for asteroid DA14 listed by the MPC. This correction is important due to the significant change in phase angle during the observations (between 50 and 75 degrees). The resulting lightcurve is shown with red crosses in Fig. 2

A set of 184 images of 1 sec of exposure time obtained with the f/8 1.5m telescope at "Sierra Nevada" Observatory (OSN) were also analyzed. The images were taken by means of a 2k x 2k cryogenically cooled backilluminated CCD, in 2x2 binning mode (resolution of 0.46 arcsec/pixel) and using no filters. The field of view was 7.8 x 7.8 arcmin. Observations started ~20 minutes before dawn, and during that time the object remained in the same star field, so no re-pointing was necessary. The image processing and data reduction was identical to that used for the "La Hita" f/3 0.77m images and described above. The photometry was obtained with respect to USNOB1 standard stars. Results are shown as blue crosses in Fig. 2.

3. Results and discussion

Using the visible and near-infrared obtained magnitudes from the photometry and the corresponding colours, we have computed the spectral reflectance R , normalized to the r' filter. We have used Sloan colors of the Sun from different sources in the literature (Sparke & Gallagher 2007; Fukugita et al. 2011). For the filters in the near-infrared, we used the colors of the Sun from Campins et al.

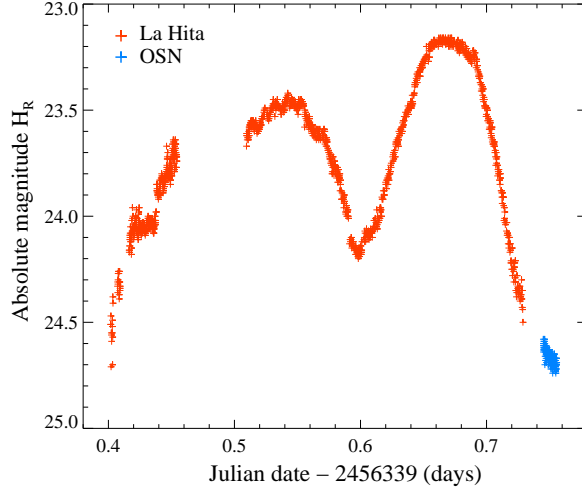


Fig. 2. Resulting lightcurve from the time series photometry done with the f/3 0.77m telescope at “La Hita” Observatory (red crosses) and the f/8 1.5m telescope at “Sierra Nevada” Observatory (blue crosses).

(1985) and Colina et al. (1996). We have also corrected R for the changing distance of the asteroid and the change in phase angle, as well as the variation in magnitude due to the rotation of the object. The computed R values with their corresponding error bars are shown as filled circles in Fig. 1, superimposed on the two visible spectra from GTC (red) and CAHA (black) in the top panel. The photometric results are in very good agreement with the two spectra.

We used the M4AST⁴ on-line tool (Popescu et al. 2012) to classify our visible spectra of DA14, obtaining a taxonomic classification as an L-type. The computed R values for the near-infrared are shown in the bottom panel of Fig. 1, together with the mean spectrum of L-type asteroids (blue line) from DeMeo et al. (2009). Light-blue dashed lines indicate the variation range of this mean spectrum. Considering the error bars, our near-infrared colors are consistent with the taxonomy obtained from the visible spectra, showing the expected behaviour for L-type asteroids: a strongly reddish spectrum shortwards of $0.8 \mu\text{m}$, and a featureless flat spectrum longwards of this, with little or no concave curvature related to a $1 \mu\text{m}$ silicon absorption band. There are almost no specific references in the literature regarding these objects, as L-type asteroids are relatively uncommon. According to Bus & Binzel (2002), although the L-class plots immediately adjacent to the S-types in spectral component space, they are considered as anomalous S-type asteroids. The majority of the objects classified as L-types belong to two dispersed groups or families in the outer main belt, the Henan and the Watsonia families. Burbine et al. (1992) analyzed the visible and near-infrared spectra of two members of the Watsonia group, finding that their spectra were most likely produced by spinel, an aluminium-magnesium oxide mineral commonly present in inclusions in CV3 and CO3 meteorites. In this sense, L-types would not follow the well know relation between the S-types and the ordinary chondrites.

In the case of the asteroid’s lightcurve, the high phase angle values at the moment of the observations probably results in shadowing effects that may show up as rapid changes in the lightcurve. The magnitude variations seen in Fig. 2 are large enough to discard actual surface variations of

⁴ <http://cardamine.imcce.fr/m4ast/>

albedo. With an amplitude (Δm) of more than 1.5 magnitudes, these changes are most likely due to the asteroid's rotation, implying a very elongated object that shows very different projected areas as it rotates. We would expect two maxima and two minima in the lightcurve during a complete rotation of an elongated object. As the two maxima we see in Fig. 2 are very different, this asteroid must be very irregular, having an axis ratio of $\sim 10^{(\Delta m/2.5)}$, i.e., a factor larger than 4. If the long axis is around 50m, as can be inferred from the latest radar images shown by NASA (<http://www.jpl.nasa.gov/news/>), the short axis would be ~ 12.5 m. Nevertheless, due to the aforementioned shadowing effect, the short axis could be larger. Assuming a size of 50x15x15 m, the asteroid's equivalent⁵ diameter would be around 22m, much smaller than the diameter estimated before the closest approach. All these suggest that approaches of objects like DA14 within the geosynchronous satellite ring are more frequent (twice a year, following Ortiz et al. 2006; once every 1.5 years according to Brown et al. 2002) than what was estimated for an object with a diameter of 50m (about once every 40 years according to NASA press releases). Regarding the absolute magnitude, we have obtained a value of $H_R = 24.1 \pm 0.2$, which translates into $H_V = 24.6 \pm 0.2$ considering the V-R color, in good agreement with the value listed by the MPC database. Using the obtained absolute magnitude and the estimated size of the asteroid, we compute an albedo of $p_V = 0.34 \pm 0.20$, which, considering the error, is in the range of albedos for S-class objects (0.15-0.20).

The rotational period of the asteroid cannot be precisely determined by our lightcurve, as it is somewhat incomplete. It seems from Fig. 2 that we missed just a small portion at the end of the rotation cycle. Therefore, the period of the asteroid must be slightly larger than the 8.6 hours that lasted our observations. This result agrees with the value between 8 and 9 hours estimated from the latest Goldstone radar images after the closest approach and reported by Lance Benner to the NASA/JPL Asteroid Radar Research⁶. While this paper was being written we learnt about a lightcurve of DA14 obtained by an amateur astronomer and posted on the internet at <http://brucegary.net/2012DA14/>. Overall, both lightcurves are similar, but not identical, perhaps because we included phase angle correction. Finally, we cannot discard that the object is tumbling. According to Burns & Safronov (1973) the dynamical time to damp a non-principal axis rotation would be in the order of the age of the Solar System for a body of the size of DA14. Unfortunately the object is now very faint and re-observing it to try to determine whether the lightcurve is repeatable will be difficult as it would require a large telescope and a large observing run.

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⁵ The equivalent diameter is the diameter of a sphere with the same volume as the object.

⁶ <http://echo.jpl.nasa.gov/asteroids/2012DA14/>
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